Pathematic Agents: Rapid Development of Believable Emotional Agents in Intelligent Virtual Environments

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Abstract

Intelligent Virtual Environments have grown considerably over the past few years. This paper presents an architecture for building Believable Emotional Agents, (which we call Pathematic[1] Agents) in Intelligent Virtual Environments and describes part of its implementation.

The architecture follows a theatrical metaphor and is divided in three modules: the dynamic script-writer (mind module), the theatrical company with its director and cast of actors (body module) and the actual settings where the action takes place (world module). The paper concentrates on the mind module implementation. The mind module uses the cognitive theory of emotions of Ortony, Clore and Collins to handle the emotion structures of the virtual agents and is inspired on Fridja's two-stage emotional stimuli appraisal theory.

This paper also describes the integration of the mind module in a real time application implementing the presented architecture. The application was exhibited in Lisbon, in the Territory Pavilion of the last world exposition of the century: Expo'98. Two synthetic dolphins, Tristão and Isolda, the main characters of this Intelligent Virtual Environment lived during the four months of the exposition and were displayed to more than one million visitors. The project was implemented under a tight schedule and showed that the architecture implementation is a viable solution for short time development of quality Intelligent Virtual Environments.

[1]Pathematic: (a. rare (ad. GR.) pathematicos - liable to passion or emotions, s. pathema - what one suffer, suffering emotions, s. stem path -:see pathetic) pertaining to the passions or emotions; caused or characterised by emotions. (Oxford English Dictionary)

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1 Introduction

The interest for user-independent activities in Virtual Environments (VE) has grown considerably over the past few years. Synthetic actors and autonomous agents are now a valued feature in single user or distributed VE. The Jack system [2], STEVE [9], Virtual Theater [10], Cosmo and Herman [11], Oz [12], ALIVE [13] and Artificial Fishes [20], are but a few examples.

Naturally, building intelligent agents for VE raised a new set of concerns for the developers. One of the major concerns is *believability*. A believable character is one that gives the illusion of life and allows the user's *suspension of disbelief* [1]. To bind the participants to the virtual characters, the positive and negative reactions of the synthetic actors have to make sense when considering their perceived or assumed goals, beliefs and attitudes [16]. To achieve believability, the behavior of the character has to be consistent with her *personality*.

Several techniques from different fields are being investigated and tested to provide higher levels of believability. Artificial intelligence and artificial life techniques are completed by drama and literary studies (e.g. [10]), neurology postulates (e.g. [5] and [8]), and psychology models (e.g. [15] and [18]), all contributing for the building of Intelligent VE (IVE).

This paper presents an approach based on techniques and models from artificial intelligence, drama and psychology to create IVE with believable emotional agents, which we call Pathematic Agents. The solution uses a theatrical metaphor and is based on an architectural framework, composed of three modules: the dynamic script-writer (the mind module), the theatrical company with its director and cast of actors (the body module) and the actual settings where the action takes place (the world module).

The paper focuses on the mind module implementation, responsible for the management of all the agents at the narrative level. The mind module was built to reduce the development time of pathematic agents, an important factor when considering IVE implementation from scratch. It bases itself on the theory of A. Ortony, G. Clore and A. Collins (OCC) [16] to handle the cognitive structure behind the agent's goals and emotions. It is also inspired on N. Fridja's two stages emotional stimuli appraisal theory [7].

The mind module implementation was used in a real time IVE. The application was developed in the context of the last world exposition of the century, Expo'98. Two synthetic dolphins, Tristão and Isolda, are the main characters of this IVE and lived during the four months of the exposition in the virtual estuary of the Sado river.

The paper is organized as follows. After a brief overview of the use of emotions and personality in the field of believable agents, the scenario for the implemented IVE is presented. Then, the architecture for IVE short time development is described. This description is followed by a high level explanation of the concepts underlying the implementation of the mind module, instanced to the practical application of the presented architecture. Finally, the results are explained and the conclusions are presented.

2 Related Work

Two main investigation directions became prominent when considering the development of Believable Agents. One direction bases itself on biology and neurology to achieve believability and rational behavior. The other takes a more empirical and artistic approach in the agent building process.

The first approach uses techniques and mechanisms from Artificial Life inspired in biological and neurological theories and postulates. The research of A. Damásio [6] is a major source of inspiration. Along with several hypotheses in neurology, it encourages the use of mechanisms as Neural Nets and Reinforcement Learning to simulate the agent behavior model. In those VE, the agents develop by themselves strategies conditioned to the characteristics of the synthetic environment they inhabit to achieve their inner goals. This process is done without the user's direct supervision. The selection of the fittest agents of a generation, used as guidelines in building birth states of newborn agents, is generally also helped by automatic mechanisms as Genetic Algorithms. The attractiveness of this approach resides in the automation and independence of the development process. One can just sit back and watch the agents (eventually) develop interesting and rational behavior. Examples of this approach can be found in Gridland [5] and Cyberlife Technology commercial product Creatures [8].

However, when the goal is to build agents with a predefined personality, this approach is inappropriate. The need for a controlled learning stage, where the desired agent behavior is built upon a set of thoroughly designed test environments for the effect, is hardly practical. The desired results are not easily controllable, not to say guaranteed. There is a need for a more practical and immediate approach, an approach built upon more empirical evidence.

A second approach appeared, following an artistic perspective. Like an actor who must interpret a well-defined role in a play, this direction of investigation focuses on the elaboration of strategies that allow the configuration of the behavior of the character to achieve a consistent exteriorization of a pre-defined persona. This is a more practical and artificial approach but a necessary one. When developing agent applications, especially when the agent function is critical, its behavior must be predictable and consistent.

A set of strategies has been developed in this direction. At Carnegie Mellon University, the J. Bates group started with linear variables to define the mood of the agents. In Edge of Intention [12], three variables depicted the physical, social and emotional dimensions of the characters (woggles) inhabiting the virtual world. At Stanford Knowledge System Laboratories, the team of B. Hayes-Roth moved a step further, incorporating linear personality traits to define the agents' behavior in their Cybercafé [19]. Again at Carnegie Mellon University, the work of S. Reilly led to the Em system [18]. Set atop of the Tok architecture [12], it allows the fusion of emotions based on the OCC theory [16] with the agent's design. Another important work in this field is the Will architecture [15] of D. Moffat. Following a similar path to B. Hayes-Roth Virtual Theater [10], a model of personality traits was used to define the personality of the agents which emotional behavior was based on Fridja's [7] theory of emotions.

The work presented in this paper follows the second approach.

3 Scenario

Lisbon held the last world exposition of the XX^{th} century: Expo'98. Its theme was "The Oceans, a Heritage for the Future". One of the greatest symbols of the oceans is the dolphin. However, and since dolphins could not be brought to Expo'98, S3A, an interactive application featuring artificial dolphins, was developed.

A team from heterogeneous fields of expertise was assembled. Biologists and ethologists from the Delphim project, a non-profitable organization devoted to the study of the Sado dolphin community, assisted the engineers in the simulation of realistic behavior and motion for the dolphins. Designers and artists from the Territory Pavilion assisted in the creation of interesting personae for the characters, in the building of an involving background history for the characters and in all the artistic aspects of the system. All gave their contribution to make this project believable and interesting, a good balance between artistic and realistic virtual expression. Tristão and Isolda were born.

S3A enables the experience of communicating with dolphins. It allows a user to influence the behavior of a bottle-nose dolphin descendant from the dolphins that once populated Atlantis waters: Isolda.

Isolda is a common Atlantic dolphin, quick and agile, that ended up on the Portuguese shore where she met Tristão, a male Sado bottle-nose dolphin. Isolda, due to her *descendance,* has faith in mankind and still has embedded in her genes the ability to sense the action of the apparatus. Tristão is a typical Sado dolphin: heavy, shy and very suspicious of men activities. He is insensible to the apparatus. Tristão and Isolda are represented in Figure 1.

Figure 1: Tristão (left) and Isolda (right)

Isolda, Tristão and the Human presence (via the ap paratus) are the vertexes of a dramatic triangle intro duced to involve the public in S3A's plot. The communication apparatus, a ceramics sculpture of a dolphin equipped with four pressure-button sensors, was laid in the middle of the exhibition room, in front of the screen as shown in Figure 2. The visitor could, at any time, approach the sculpture and touch one of the buttons to influence Isolda's emotions.

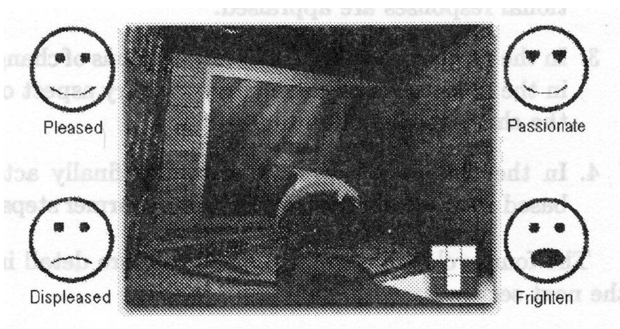

Figure 2: Interface and Sensors

4 Architecture Overview

This section presents the IVE architecture. It follows the second line of investigation, that is the artistic perspective, providing a framework for the creation of IVE inhabited by characters with predefined emotional profiles.

The architecture uses a theatrical metaphor and is divided in three main modules: the mind module, the body module and the world module. The overall architecture of the IVE is represented in Figure 3.

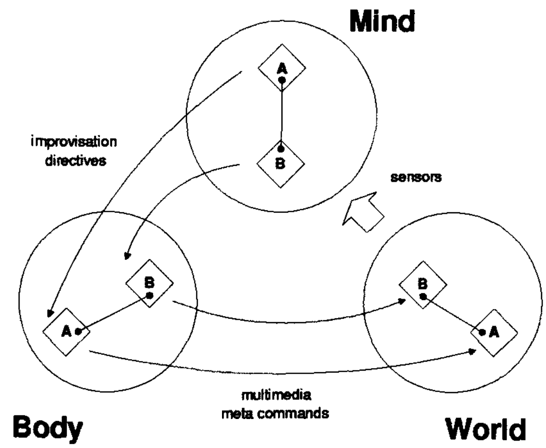

Figure 3: IVE Overall Architecture

The designations mind, body and world are used to provide a bridge to the vocabulary used in most agents systems but their meaning is slightly different in the context of this paper.

Each module implements a specific part of all the agents of the IVE. Each part of an agent can communicate with all the agent parts in the same module but only with the parts of the same agents in the adjacent module. For instance, the mind of an agent can communicate with all the agents minds of its IVE but only with its body implementation. Assuming that each part is interested in a particular type of data, the idea is to restrict the communication between modules, therefore allowing highly parallel development of the IVE and thus reduce the overall development time. The one-way communication between modules strengthens this idea. On the other side, the tight integration of each module allows the development of efficient implementation strategies to allow the architecture to be used in real time IVE.

The next subsections describe in more detail each module architectural purpose.

4.1 Mind Module

The mind module can be viewed as a dynamic script-writer. It is responsible for managing all the agents, taking all the decisions relevant to the story and dynamically generating the storyboard. At each step of the process, it must generate a new set of improvisation directives for each actor of the story, taking into account all sensor data received since the last step of the storyboard it generated. The narrative emerges from the individual actors' behavior. The improvisation directives are then passed to the body module.

The time span between two consecutive steps of the mind module is designated *narrative time*. It is a subjective time span that represents the time for something relevant for the storyboard to be planned and executed.

4.2 Body Module

The body module can be viewed as a theatrical company director and her set of actors. The improvisation directives received from the mind module are the set of commands that the actors must fulfil. They must follow accurately the script but can improvise on it as long as they still convey to the viewer the actions specified by the improvisation directives (directed improvisation paradigm) and stay "in character". They use the classical *Commedia del'Arte* improvisation guidelines as used in [10]. Like Humans improvisers, the agents are intended to work together to produce engaging performances. For example, they must: accept all offers, do not block other actors, act naturally, do not try to be clever and re-incorporate previously generated elements. The director is responsible for handling each actor and planning her performance into sequences of actions that do not hinder other actors' performance. It is also responsible to handle possible interruptions and exceptions. Thus, the body module ends up controlling the simulation time. It computes low-level audio and geometrical primitives and output them to the world module. It also monitors the progress of all improvisation directives. When all have been performed, the body module fetches a new set of directives from the mind module. Since new improvisation directives are only fetched when all actors have performed their actions, some will perform quicker than others. At this point, improvisation comes into play. Actors must continue to perform accordingly to their recent actions and emotional state until a new set of primitives is retrieved from the mind module.

The time span between two consecutive steps of the body module is designated *simulation time*. It is the time used in each simulation cycle for actuation planning and geometry and audio calculations.

4.3 World Module

The world module is responsible for translating the low-level primitives sent by the body module into audio-visual output. It is also responsible for reading the sensors, which data is out-putted at each cycle to the mind module which stores the information to be used in the next narrative cycle. Typical tasks of the world module consist in managing the camera and "stage" special effects.

The time span between two consecutive steps of the world module is designated *visualization time*. It is the time used in each simulation cycle for geometry rendering, audio playing and sensor reading.

5 Mind Module Implementation

The mind module, alias the dynamic script-writer, is responsible for managing all the agents, taking all the relevant decisions relevant for the story and dynamically generates the storyboard for each character accordingly to their persona. To achieve this goal, the mind manipulates a set of concepts that abstractly represents what is going on in the VE. The concepts and their implementation are explained in [14].

The character behavior implementation is based on ideas taken from two psychological theories of emotions: OCC cognitive theory of emotions [16] and Fridja theory of emotions [7]. The OCC cognitive theory of emotions provides the basis for modeling inner interactions between emotions and goals in terms of behavior repercussion. Fridja's two-stage appraisal theory provides the basis for the character perceive-react-reason-and-act cycle.

Each **character cycle** is divided into four phases

1. In the **perception phase**, the events of the world are filtered according to the characters interests and location. Each character also updates its model of the world in this stage.

2. In the **reaction phase**, the immediate impact of events on the characters is estimated and emotional responses are appraised.

3. In the **reasoning phase**, the implications of changes in the internal world model and on every aspect of the character life are evaluated.

4. In the **action phase**, the character finally acts based on the evaluation performed by former steps.

The four-cycle steps are explained in more detail in the next sections.

5.1 Perception Phase

5.1.1 Event Filtering

"Characters do not perceive all the events of the VE."

Characters have a limited perception capacity. They only perceive events happening in the area where they stand. All events outside their location area are discarded. Additionally, characters only perceive events that are relevant for their concerns [7]. The events of the world are chosen selectively through a set of filters. The *filters* are specified as a set of action patterns and represent the character interests, major needs and preferences. All events not matching the filters are discarded.

5.1.2 World Model

"Characters do not perceive the virtual world as it is."

To model this discrepancy, characters have entity models. *Entity models* are subsets of parameters associated with an entity that are updated as the events of the world are perceived. They represent the immediate aspects of entities relevant for a specific character. The non-immediate aspects of entities are handled in the reasoning stage. Decisions are always based on the world models, never on the events perceived from the VE.

5.2 Reaction Phase

5.2.1 Goals

"Characters react based on inner goal repercussion."

Characters have *goals* which implementation is inspired in the OCC theory. Each goal has three important attributes: the *likelihood of success* quantifies the perceived chances of the goal succeeding; the *importance of success* quantifies the relevance for the character of being well succeeded in achieving that goal; the *importance of failure* quantifies the relevance for the character of failing in achieving that goal.

Although we consider the likelihood of success and the likelihood of failure complementary, the concepts of importance of failure and importance of success are considered separately. They are not necessarily complementary.

For instance, dolphins have a replenishment goal for breathing which has a cyclic activation period. Dolphins consider natural to breathe, so success is not important at all: dolphins do not feel joy each time they breathe. But if a dolphin perceives itself as unable of breathing, it will feel an intense fear, not to say panic. Failure in breathing is an important matter and managing to breathe in those situations will most certainly provoke a very strong sentiment of relief.

5.2.2 Goal Graph

Following the OCC theory, the goals of the characters are organized as a graph. Each goal has list of goals activated on its own activation and a list of goals deactivated when the goal is deactivated. This activation implements the parent relationship between goals.

But goals are also connected through four types of semantic links: *necessary link* (if the goal fails, the linked goal fails); *sufficient link* (if the goal succeeds, the linked goal also succeeds); *facilitative link* (when the goal succeeds, its linked goal likelihood of success increases by a predefined amount); and *inhibitory link* (when the goal succeeds its linked goal likelihood of success decreases by a predefined amount).

In each reaction phase, the character goals are checked for activation, deactivation and goal likelihood changes. When a goal succeeds or fails and is deactivated, the goal graph is updated according to the link semantics.

For instance, the breathe goal has a sub goal: move up. If breathe is activated, so will move up, the same happening on success or failure deactivation. Move up is a necessary goal for breathe: if it fails, so will breathe.

5.2.3 Emotions

"Characters react emotionally to what surrounds them."

Characters display emotional responses. After filtering the perceptual information, the characters react instinctively to the set of events perceived and goal alterations.

The mind implementation considers the twenty-two base emotions of the OCC cognitive theory. As proposed in this theory, *emotional reactions* are divided in three categories:

- Emotions based on *aspects of objects*, appraising the liking of entities (agents or objects) with respect to the agent attitudes.
- Emotions based on *actions of agents*, appraising the approval of the actions with respect to the agent standards of behavior.
- Emotions based on *consequence of events*, appraising the pleasingness of events with respect to the agent goals.

The complete classification is presented in Figure 4.

Each time an emotion is created, the events, goals and entities that triggered it are used to calculate an emotional *potential*. If the potential is above a *threshold* (representing the resistance of the character for that emotion class), the emotion is said to be active and its *intensity* is calculated. As time passes, emotional intensity decays. Each character holds a *decay rate* for each emotion class (influencing the permanence of the emotion in her memory). Emotion thresholds and

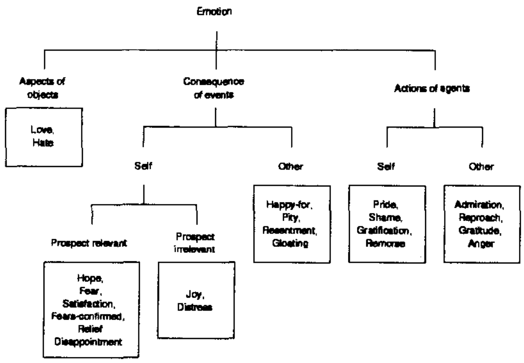

Figure 4: Emotions by Type

decay-rate are used in the character design to implement part of their personality. Additionally, each emotion stores its *cause* (entity, event or goal) and the entity towards which it is directed (*direction*).

5.2.4 Emotional Reactions

The creation of emotions is handled by the emotional reaction (*e-reaction*) mechanism. Each type of emotion has an associated e-reaction mechanism, as follows:

- *Attraction reactions* handle emotions related with aspects of objects. They are triggered by the proximity of relevant entities.
- *Event reactions* handle emotions related with consequences of prospect irrelevant events. They are triggered by pattern matching on perceived events.
- *Prospect reactions* handle emotions related with consequence of prospect relevant events. They are triggered by goal changes.
- *Attribution reactions* handle emotions related with actions of agents. They are triggered by pattern matching on perceived events with respect to the character's standards of behavior.

The four reaction types automatically handle emotional responses following the OCC cognitive theory of emotions. The character's *emotional profile*, a set of patterns mapping the character persona into reaction matching components, is implemented by a set of e-reactions. This approach follows the idea that emotions and personality are essentially the same mechanism [15].

But emotions are not only a reaction process. Emotions which are a result of thought, (e.g. hating someone for sending someone else do bad things for her), are implemented later in the cycle, at the reasoning stage.

Here are some e-reaction examples. The event/e-reaction/emotion involved are presented for each case.

"Tristão, our male dolphin, hates human-made objects. When he comes near an element of the dark plane crash pieces, he feels hate toward it."

event	proximity of a *DWreck* entity
e-reaction	negative appeal attraction reaction
emotion	**hate** (aspect of object) cause - *DSouthWreck* direction - *DSouthWreck*

"As Isolda, its female companion, approaches such hideous artifacts, he admires her courage."

event	action pattern match: *"DDolphin explores DWreck"*
e-reaction	positive praiseworthiness attraction reaction performed by another character
emotion	**admiration** (action of agent) cause - *DIsolda explores DSouthWreck* direction - *DIsolda*

"When Isolda calls its name he feels joy."

event	action pattern match: *"DDolphin calls"*
reaction	positive desirability event reaction
emotion	**joy** (consequence of event) cause - *DIsolda calls*

"When Tristãos stomach takes control of his body, he starts a new goal: eat prey. He feel hope as its likelihood is high - he rarely miss his prey."

event	Goal *GEatPrey* activation (changes of likelihood)
e-reaction	high likelihood prospect based goal
emotion	**hope** (consequence of event) cause - *GEatPrey*

"When he finally gets his prey he feels satisfied."

event	Goal GEatPrey deactivation (success)
e-reaction	Success prospect based reaction over Hope emotion
emotion	**satisfaction** (consequence of event) cause - *GEatPrey*

5.2.5 Behavior Features

"Each character expresses her emotions differently."

To enable a different exteriorization of the same emotions by different characters, the concept of *behavior feature*, suggested in the OCC theory and inspired from the implementation in [18], was introduced. It is an indirection layer, mapping the emotions into a set of concepts representing aspects of the personality of each character. They are essential to allow different characters to express themselves in a different way, even under the influence of the same emotions with the same intensities.

Behavior features are calculated based on the active emotions intensity. Each behavior feature is the weighted-sum of all emotion classes.

For instance, two of Tristão's behavior features are: good-mood and bad-mood. The intensity of the good-mood behavior is the sum [2] of the positive emotions. The negative ones sum up for the bad-mood behavior.

5.3 Reasoning Phase

"Characters infer new knowledge from new facts."

The characters infer on the information they hold on the world through entity models. At this stage, each character has selectively divided her perceived events per entity (subject or object of an action) and now infers alterations on the world model of the respective entity.

The thought process is implemented as a set of production rules. The results of the reasoning process update the characters internal state and world models. For instance, emotion thresholds and decay-rate may be adjusted to reflect a particular mood of the character. Additionally, moods may change perception filters.

5.4 Action Phase

5.4.1 Resources

"Characters act according to resource availability."

Characters actions use resources. A *resource* is an abstraction over the availability of means to perform an action. Only one action can use a resource in a narrative cycle. Therefore, characters can perform several actions at the same time if the actions performed do not share the same resources. This approach is inspired in Alive Silas T. Dog [3] and the Improv System [17].

For instance the dolphins have a resource for each physical part of their body: the head, the mouth, each one of the fins and the tail. If the mouth is used to eat something then it can not be used for anything else in the same narrative cycle.

5.4.2 Priority Planning

"Characters act according to the actions' importance."

As reasoning, planning is implemented through a set of priority production rules. The planning implementation is based on the goal implementation.

Each goal has a *priority*. When several goals are active at the same time, the respective set of production rules (*action rules*) becomes active. All action rules not verifying behavior features restrictions are deactivated.

[2]This is not the arithmetic sum but the desired effect is similar: to add emotional intensities [14]

Active action rules are then organized by resource. For each resource, the action for the highest priority goal is fired: the character acts.

Actions are exteriorized as a set of improvisation directives sent to the body module and to the mind pool of events so they can be used as sensorial information in the next characters cycle. Note that characters perceive and react to their own actions.

The approach of competing actions and resources is inspired in Brooks' subsumption architecture [4] and Blumberg's multi-level goal architecture [3].

6 Results

The application ran non-stop during the four months of the exposition and was displayed to more than one million visitors (an average of 10,000 per day).

Two aspects of the project must be considered separately: the technical viability of the architecture and the mind implementation and; the emotional believability of the created characters.

6.1 Technical Viability

S3A was developed from scratch in less than four months by a team of 15 persons (7 coders) for a total effort of 20 persons-month. The modules weak dependencies allowed the parallel development of the three modules, thus reducing the overall development time.

Regarding performance, the mind module implementation confirmed the viability of its integration in a real time full 3D IVE with minimum performance degradation on mid-range graphical systems. The application ran on an Intergraph Realizm2 (25k polygons, 40MB textures) at about 12 frames per seconds. As expectable, the bottleneck was the simulation cycle.

The main benefit of using such architecture is the communication reduction since it is localized and mostly unidirectional. Additionally it allows each team to develop adequate solutions for their particular problems without a constant synchronization need.

The principal flaw of this approach is the need for information redundancy in the modules to reduce communication flow. But this is an acceptable drawback, when striving for independence in development and real time achievement.

6.2 Emotional Believability

The prime requisite of the project was that the simulation had to be faithful to real life: dolphins could not perform actions they would not do in the real world. Emotional expression could not be exaggerated to convey clearly the emotional state of the characters, a technique used by character animators [1]. The challenge was to use the real world behavior of dolphins to make the visitor understand the human personalities attributed to the main characters ([14]).

For a visitor to understand the personality of the actors, she has to take some time to observe them interacting with the environment or, at least, be briefed about their habits and behavior. In the context of a world exposition pavilion with no guided tour and a high visitor throughput, this was rarely the case. Thus, if the people supervising the exposition rooms perfectly understood the dolphin behavior after some time, the same could not be said about the average visitor who spent no more than a couple of minutes in the room.

If the behavior was rational and realistic, according to ethological data, the emotions were not always undoubtedly perceived. To overcome this problem, sensor high priority rules overrode the dolphin behavior. For instance, even if Isolda was in highly need of oxygen, she would perform a happy behavior (e.g. a loop) if a user pressed the pleased button. This was as far as we could go to convey immediate perceivable behavior without ruining the realism of the simulation. The behavior interruption was not perceivable by the user since it is very hard for a visitor to guess what are the designs of a swimming dolphin.

Thus and considering the user perspective, the dialectic between artistic and real world simulation was the major influencing factor explaining the obtained results.

7 Conclusion

An architecture for rapid development of IVE and the implementation of the mind module, the module controlling the agents narrative behavior, were presented. A specific case of application of the architecture in the creation of a full 3D IVE was described. The application confirmed the viability of the architecture and the mind module for rapid development of real time IVE. Although the aspect of emotional believability was not undoubtedly achieved, the architecture confirmed its suitability for implementing believable characters.

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